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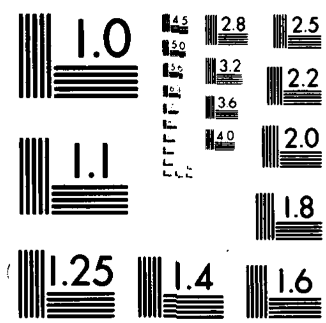

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HELICOPTER EXTERNAL CARGO SLING APEX FITTING — DEVELOPMENT AND TESTING

Randy L. Crane, Harvey D. Goff
FIBER SCIENCE, INC.
506 Billy Mitchell Road
Salt Lake City, Utah 84116

November 1980

Final Report for Period April 1977 - May 1980

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APPLIED TECHNOLOGY LABORATORY
U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)
Fort Eustis, Va. 23604

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

The Kevlar external cargo sling apex fitting concept described in this report represents a significant improvement over the current steel and aluminum apex fitting in reduced weight and ease of operational handling. Twenty-two Kevlar apex fittings were delivered to the Government under this program and will undergo further laboratory and operational testing by the Army and Marine Corps. The Kevlar apex fitting with final refinements will offer a replacement to the current metallic hardware.

Richard E. Lane of the Aeronautical Systems Division was the project engineer for this effort.

DISCLAIMERS

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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Composite materials
Experimental design
Manufacturing methods
Test and evaluation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A one-piece helicopter external cargo sling apex fitting was developed from Kevlar 29 to meet Army requirements for a lightweight, nonmetallic fitting that will facilitate cargo hook movement of sling-assisted loads. This report outlines the processes of material selection, design concepts, manufacturing methods, and testing undertaken to develop a versatile unit that meets or exceeds all previous criteria.

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SUMMARY

In fulfillment of Contract DAAJ02-77-C-0026, Advanced Technology Sling Fitting (Apex Fitting), Fiber Science, Incorporated, 1) investigated currently available composite (nonmetallic), high strength-to-weight materials; 2) identified designs and fabrication techniques that resulted in the lightest possible apex fitting designs capable of satisfying minimum performance requirements; 3) fabricated and tested seven 25,000-pound capacity (25K) and seven 40 000-pound capacity (40K) fittings; and 4) fabricated eighteen 25K and four 40K fittings for field evaluation.

The apex fittings which Fiber Science, Inc., developed are a one-piece Kevlar 29/Epoxy design weighing 1.6 pounds for the 25K and 3.0 pounds for the 40K models. These fittings are compatible with current helicopter cargo hooks, will maintain structural and dimensional integrity at maximum loads in all temperatures, and can be used without tools while wearing arctic gloves.

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INTRODUCTION

The apex fitting is used to gather the legs of a sling assembly to form a convergent point for attachment to the helicopter cargo hook. The current apex fitting is a heavy steel clevis which is difficult to handle and inconvenient to assemble. The objective of this task was to design and fabricate a lightweight nonmetallic sling apex fitting with a minimum number of component parts that would be safe and easy to use. The apex fitting developed by Fiber Science, Inc., fabricated from Kevlar 29, fills this objective.

MATERIALS SELECTION

A primary requirement for the reinforcing fiber in composite materials is that it be strong and continuous in length. Short fibers, i.e., whiskers, were not investigated because they suffer too much loss of unidirectional strength. The available fibers considered were glass, graphite, Kevlar, and boron filaments. Resin matrices have been used with all the above materials and an aluminum matrix has been used with boron filaments. A properties and cost comparison is given in Table 1.

Although E-glass is slightly less expensive, its physical properties are lower than all other materials evaluated. It was, therefore, not considered as a candidate.

TABLE 1. COMPOSITE PROPERTIES AND COST

	E-GLASS	S-2 GLASS	KEVLAR 29	GRAPHITE (THORNEL 300)	BORON/ EPOXY	BORON/ ALUMINUM
Fiber Cost, \$/lb	0.48	2.33	9.75	32.00	200.00	200.00
Resin Cost, \$/lb*	8.25	8.25	8.25	8.25	8.25	-
Composite Raw Matl. Cost, \$/lb	2.51	3.93	9.12	23.29	142.50	-
Fiber Volume, %	55.0	55.0	55.0	55.0	50.0	50.0
Resin Weight, %	26.82	27.25	39.15	34.64	30.25	51.28
Composite Density, lb/in.^{3}	0.0691	0.0680	0.0474	0.0535	0.0677	0.0975
UNIDIRECTIONAL ORIENTATION						
E_x, 10^6 psi (elastic modulus)	5.986	7.141	9.00	18.91	29.0	33.75
E_y, 10^6 psi	0.274	0.274	0.235	0.567	1.0	4.0
F_{tu}, psi (failure strength)	151,000	178,800	178,800	178,800	220,000	220,000
F_{cu}, psi	102,000	118,300	38,500	118,300	255,000	-
F_{su}, psi	5,700	5,700	2,800	4,400	9,000	-

*3M 2216 B/A Clear Amber

E_x - elastic modular in the X direction
E_y - elastic modular in the Y direction
F_{tu} - failure strength tension
F_{cu} - failure strength compression
F_{su} - failure strength shear

Boron/aluminum was eliminated quickly based on density, cost and fabrication considerations. The cost figure is for materials only. If fabrication costs were included, boron/aluminum would be more expensive by another factor of 10.

Boron/epoxy is more favorable in density than is boron/aluminum and manufacturing costs are also lower. However, on a cost and weight basis, the boron/epoxy is not competitive with Kevlar and graphite.

One of the greater handicaps of boron filaments is the difficulty in handling. Filaments are easily collimated and hot melt coated with resin to form a prepreg. However, it is very hard to wind sheets, or even filaments, into small radius shapes. Handling and manufacturing problems with boron in a filament winding application were beyond the scope of this program; hence, boron epoxy was dropped from further consideration.

Graphite and S-2 glass compare favorably except in cost and modulus. Graphite is higher in both of those factors and somewhat lower in density. Since cost is a program consideration, it was determined that higher physical properties did not offset the cost, therefore, S-2 glass must be selected over graphite as a low cost material solution.

Kevlar is unique in having low density, high modulus, high tensile strength and reasonable cost. Kevlar 29 has double the allowable strain of Kevlar 49; this allows more fibers to carry a load during intended use. Based on all of these characteristics, Kevlar 29 was selected as the material for fabrication of apex fittings. (See Appendix 1 for detailed material characteristics.)

The chosen design and manufacturing technique required a resin with high elongation to permit some flexibility in the completed part. This was the primary reason for selecting 3M "Scotch-Weld" 2216 B/A clear amber resin. (See Appendix 2 for properties and performance characteristics.)

ENVIRONMENTAL COMPATIBILITY

Kevlar 29 has good thermal stability, retaining virtually all of its room temperature properties at temperatures of -50° F to 320° F. At arctic temperatures it exhibits essentially no embrittlement or degradation of fiber properties.

Kevlar rope, 1/2-inch diameter, exposed to the Florida sun for 6 months showed a 10-percent degradation in strength. A coating of clear resin will reduce the degradation to less than 10 percent.

If a pigment was used in the resin, it is expected that very little degradation would take place.

Although there is no published information on environmental characteristics of the resin, it is known to break down under prolonged exposure to ultra-violet rays. Resin in the apex fitting holds the fibers in place but does not carry a load. Because the fibers are compacted very tightly, it is doubtful that resin degradation would occur beyond a depth of .10 inch, which could result in some loose surface fibers. As mentioned above, a pigmented surface coating or pigment in the resin should correct this degradation.

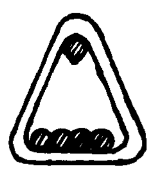
DESIGN CONCEPT

The relatively low density and high tensile strength of the filament-wound composites discussed previously have led to the possibility of fabricating apex fittings from them. The fitting must be useable in arctic weather by personnel wearing heavy gloves and must also be operable without using tools. The fitting must be sized to take a variety of cargo hooks.

Several concepts were considered. Bending must be minimized so that the sling legs are not pinched. Because bending is accompanied by shear stresses, this becomes an important design consideration due to relatively low composite interlaminar shear strengths.

An initial shape concept, without worrying about the mechanics of using it, was a triangle:

Any of the three apexes can be used to engage the hook, but the sling legs do not fill out the opposite side of the triangle. Slings can shift, making the triangle unstable. If one side of the triangle is shortened, thus:



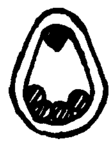
instability is reduced but it is possible to get the hook in the wrong corner and induce an instability.

A circular fitting almost maximized bending and is, therefore, eliminated.

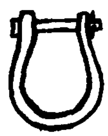
An oval shape can be designed to accomodate the sling legs:

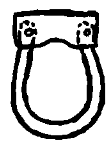
But now, with that configuration, the opening for the hook is too large, which induces point loading and extra bending.

A modified oval was finally selected as the best compromise shape;



A secondary feature for the fitting is some mechanism to open and close it so that sling legs can be inserted. If the hook end of the fitting is removable, the slings have to go to the correct end of the fitting. Two variations were considered for Concept 1 (a single hookup of four sling legs):





The first variation required a steel pin to be inserted into the shackle and then either pinned or threaded in place. Either method is hard to do while wearing gloves and the pin could be dropped and lost.

The second variation was a hinged I-beam to close the shackle. The I-beam is superior to a pin in that it can be designed for a given stiffness and a minimum weight. The hinge is simply a pin that cannot fall out. However, a closing pin is also required and it presents many of the handling problems of the first variation. These problems can be corrected by attaching the pin to the hanger with a chain and then locking it on the opposite side with a large spring. The spring is pressed to open up and then is locked around the pin. The pin has an oversize head and stands away from the hanger on a shoulder so that it can be grabbed easily, even with a mitten.

The Concept 2 fitting (for a double hookup of two sling legs each) is basically two Concept 1 fittings connected with a spring clip. The spring clips can be used to lock two fittings together. If single fittings (Concept 1) are needed, two spring clips are pulled out and stored by rotating them 90° and reinserting one clip into each fitting.

The most promising design proved to be an elongated figure 8 with a 180° bend at the center section (see Figure 1). This configuration provides a saddle for the cargo net loops to set in without concern for stability.

Figure 1. Fiber Science Apex Fitting.

MANUFACTURING METHODS

The first method of fabrication was: (1) wind the rovings around a two-post mandrel; (2) remove the wet laminate and place it in a forming mandrel to provide hoops for the hook end; (3) twist the laminate in the center to form a figure 8; (4) place the center of the figure 8 over another mandrel and bend the laminate until the two hook ends meet, thus forming the cargo net loop at the bend; (5) cure the sling.

During the winding process the fiber tension was held as low as possible to avoid the cutting action of fibers as they imbedded into the fibers already wound. The part was then placed in a tensioning box to uniformly load each fiber. The cured part has maximum strength when each fiber carries the same load as soon as tension caused by the weight being lifted, is initiated.

Initial testing of parts made by this first method indicated that all fibers were not uniformly preloaded which caused progressive failure of fibers through the part as tension was increased. Review of this fabricating method indicated that repeated handling of the wet rovings in Steps (2), (3), and (4),above, caused fibers to creep, wrinkle and lose the ability to uniformly carry their loads. These deficiencies were corrected by the second method

of fabrication, which used a three-point mandrel to wind and cure the part in the shape desired (see Figure 2).

This new method of winding and curing the apex fitting on the same mandrel proved to control uniform fiber tension throughout the part because the fibers were not disturbed as they were in Method 1. Fiber tension during winding was maintained at approximately three pounds per roving by the dynamic friction between the bobbin and carriage. This higher tension increased the compaction of the fibers (compared with Method 1), making a stronger part. The three point mandrel also created a desireable fiber cross-over pattern at each end of the fitting which increased the shear strength in these areas.

The second method of winding also reduces the fabrication manhours and could be used in production. Quantity production would be achieved through automation, including tooling, to produce several fittings on one machine at the same time.

Quality control has been minimal during this development effort and consisted mainly of verifying material to proper certifications, counting the number of fibers wound into the part, and controlling cure temperatures and time.

TEST RESULTS

Initial testing of the apex fitting involved more than just the 25K and 40K units and was conducted by Osborne Laboratories, Inc., as documented by their letter report in Appendix C. The test units were fabricated by the first method (two post mandrel and no fiber tension) and tested on a fixture identical to the winding mandrel, which had large round attach points for both cargo hook end and sling end of the fitting. This provided an ideal loading condition, which was reflected in the test results. The wide scatter of data during these tests is attributed to the method of winding and forming which disturbed the fibers so that they did not carry uniform loads.

Subsequent tests were performed by the Applied Technology Laboratory, at Fort Eustis, using a test fixture which more realisticallly represented a lifting hook and cargo slings.

Initial units proved to be too small and, therefore, failed at relatively low loads. Several design modifications resulted from this testing program. First the thickness of the legs was increased; next the legs were lengthened to reduce bending stresses in the cargo loop end. Finally the cargo loop size was increased for a better load distribution of the cargo slings.

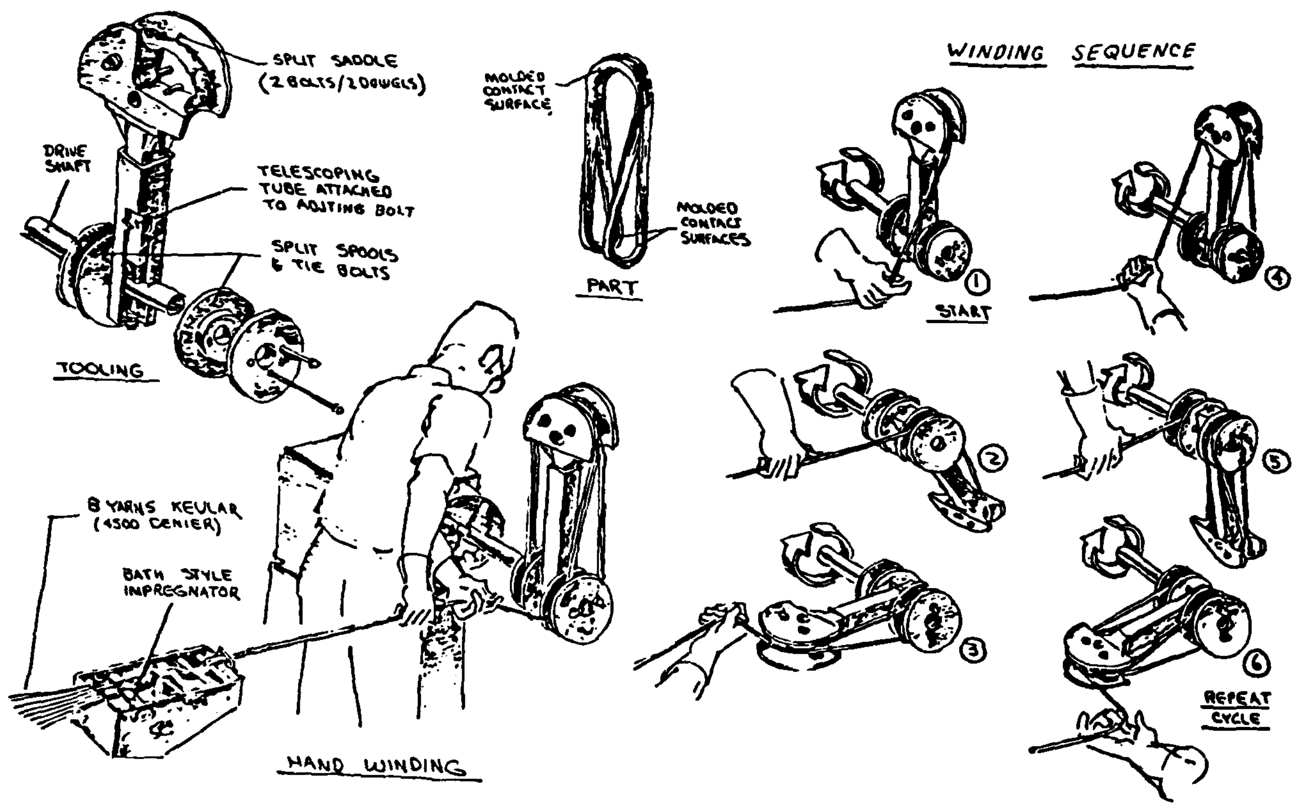


Figure 2. Apex Fitting - Tooling and Manufacturing Method.

The final configuration test results are shown on Table 2 and graphically shown in Figure 3.

Each design modification increased the strength of the fitting. When the test of 21 November 1979, substantially exceeded the maximum requirements, the wraps on subsequent fittings were decreased to make the fittings weigh less and, therefore, easier to handle.

TABLE 2. ATL TEST RESULTS - FINAL CONFIGURATION

DATE SHIPPED	WEIGHT (LB)	WRAPS	ROVINGS- 4500 DENIER	FAILURE (LB)
(25K Requirement)				(86,250)
A. 21 Nov 1979	1.8	130	8	122,000
B. 5 Dec 1979	1.6	100	8	111,000
C. 1 Feb 1980	1.6	90	8	99,750
(40K Requirement)				(138,000)
D. 21 Nov 1979	3.8	240	8	175,000
E. 5 Dec 1979	3.4	185	8	156,750
F. 1 Feb 1980	3.0	175	8	140,500

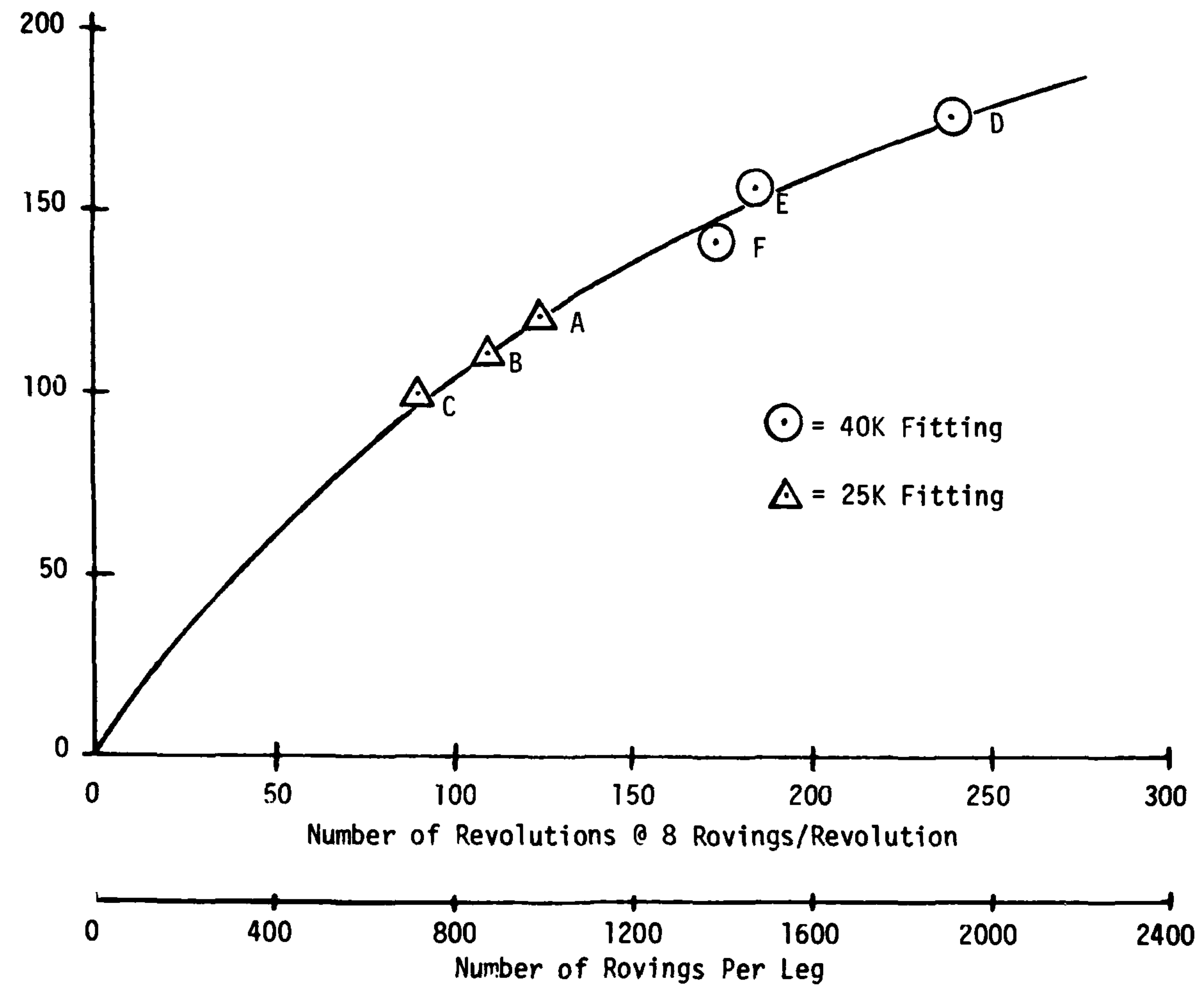


Figure 3. ATL Test Results - Final Design Apex Fittings.

CONCLUSIONS

1. The final configuration shown in Figure 1, fabricated from Kevlar 29, as shown in Figure 2, meets all requirements set forth in the contract. These apex fittings are compatible with existing cargo hooks and accept two or four sling legs that cannot shift; therefore, the fittings retain dimensional stability. Because they are nonmetallic, they are lightweight (the 25K fitting weighs 1.6 lbs., the 40K fitting weighs 3.0 lbs.) yet still exceed the strength requirements. The single part design and lightweight facilitates its full operational use without tools and even while wearing arctic gloves. Although the environmental compatability of the finished parts was not proven through testing, the published data on materials used and the contractor's experience indicates the fittings will maintain their structural and dimensional integrity in their working environment.

2. Estimated unit cost in production:

   Although a detailed study of production methods was not included in this project, the following prices have been estimated:

	25K	40K
Nonrecurring Tooling	$45,000.00	$65,000.00
Unit Price After Tooling	$ 79.50	$ 106.25
Unit Price if Tooling is Amortized Over 1,000 Units (includes interest in tooling cost)	$ 128.55	$ 177.10

3. This program has resulted in the successful development of a lightweight simplified apex fitting for helicopter sling load application. The fitting is easier to use than the present pinned steel clevis fitting and is significantly lighter. The 40,000-pound-capacity Kevlar fitting is lighter than the existing 25,000-pound-capacity steel clevis. The cost in quantity production is very competitive with the existing units.

RECOMMENDATIONS

1. Fabricate fittings with (a) pigment in the resin, (b) coating of pigmented resin or paint, and (c) present fitting for field test.

2. Test the fittings in various field environments to determine environmental compatability and life expectancy.

3. Redesign the lifting hook assembly to be compatible with composite apex fitting, i.e., generous radiuses on all corners.

4. Apply the basic design approach to sling eyes and other lifting devices.

5. Investigate developing a Kelvar tape to replace the roving in the winding process to simplify fabrication, increase shear strength and decrease the fittings weight.

6. Investigate manufacturing refinements for volume production at reduced cost.

APPENDIX A. CHARACTERISTICS OF KEVLAR 29 ARAMID

(Source, Technical Bulletin, E.E. DuPont de Nemours)

Kevlar is the registered trademark for one member of DuPont's family of aromatic polyamide fibers, which have been granted the generic name "aramid" by the Federal Trade Commission. Kevlar 29 has a tensile strength of 400,000 lb/in^2 (2758 Mpa$^+$) and modulus of 9 million lb/in^2 (62 000 MPa).

The physical properties of Kevlar 29 aramid fiber compared with those of conventional industrial nylon, Dacron polyester, fiberglass and stainless steel are shown in Table A-1. It can be seen that the tensile strength of Kevlar 29 is more than twice that of nylon or Dacron, 15 percent greater than that of E-glass and 60 percent greater than that of steel. Modulus, or stiffness, is more than 10 times that of nylon, almost 5 times that of Dacron, and is almost equivalent to that of E-glass. The fiber elongation-to-break is quite low compared with that of other organic fibers, and the density, while higher than that of nylon or Dacron, is about 1/2 that of glass, and 1/5 that of steel.

TABLE A-1
COMPARATIVE YARN PROPERTIES

	KEVLAR 29 Aramid	Nylon Type 728	DACRON Polyester Type 68	E-HTS Glass	Stainless Steel
Tensile Strength, lb/in^2	400,000$^{(a)}$	143,000$^{(a)}$	162,500$^{(a)}$	350,000$^{(b)}$	250,000
(MPa)	(2758)	(985)	(1120)	(2412)	(1724)
Modulus, lb/in^2	9,000,000	800,000	2,000,000	10,000,000	29,000,000
(MPa)	(62000)	(5512)	(13780)	(68900)	(199800)
Elongation to Break, %	4.0	18.3	14.5	3.5	2.0
Density, lb/in^3	0.052	0.041	0.050	0.092	0.284
(g/cm^3)	(1.44)	(1.14)	(1.38)	(2.55)	(7.83)

(a) Unimpregnated Twisted Yard Test - ASTM D2256
(b) Impregnated Strand Test - ASTM D2343

Kevlar 29 also has high toughness which yields good textile processibility and high impact strength; for example, loop strength is 55% of straight breaking strength.

Kevlar 29 has good thermal stability, retaining a high percentage of room temperature properties when tested up to 355^{o} F (180^{o} C). The fiber exhibits virtually no shrinkage between room temperature and 320^{o}F (160^{o} C). Kevlar 29 does not melt or support combustion under normal environmental conditions but will carbonize at about 800^{o} F (427^{o} C). At arctic temperatures of -50^{o}F (-46^{o} C), it exhibits essentially no embrittlement or degradation of fiber properties.

The chemical resistance of Kevlar 29 is excellent except in a few strong acids. The effect of ultraviolet light will vary with the thickness of the item exposed. Very thin fabric (4.5 mil, 0.114 mm), if exposed directly to Florida sunshine for a period of 5 weeks, will lose about half of its tensile strength. In thicker items, such as the 1/2 in. (12.7 mm) diameter rope, the majority of the yarns are protected by the outer layer and the strength loss is minimal. Although self-screening may be sufficient for some applications, the addition of opaque jacketing may be required for increased UV resistance under critical conditions.

Kevlar 29 has an equilibrium moisture level of 7-percent at 72^{o}F (22^{o} C) at 55 R.H., and a negative coefficient of thermal expansion of $-2 \times 10^{-6}/^{o}$ C ($-1.1 \times 10^{-6}/^{o}$ F).

Kevlar 29 has excellent dynamic and static fatigue resistance, as well as stress relaxation behavior. Creep rate is equivalent to that of fiberglass, but unlike glass, is much less susceptible to creep-rupture, even at levels as high as 70-percent ultimate tensile strength. Additional information on creep, fatigue, and impact properties is available upon request.

APPENDIX B. CHARACTERISTICS OF "SCOTCH-WELD" STRUCTURAL ADHESIVE, 2216 B/A CLEAR AMBER

(Source: Technical Bulletin, 3M Company)

"Scotch-Weld" transparent, flexible, two-part, room temperature curing structural adhesive with high shear and peel strengths. Used for bonding rubber, metal, wood, most plastics and masonry products.

TABLE B-1. "SCOTCH-WELD" PHYSICAL PROPERTIES

	BASE	ACCELERATOR
Color	Transparent	Amber
Base	Modified Epoxy	Modified Amine
Net Weight (lbs./gal.)	9.6	8.2
Viscosity (approx. cps @ 75°F.)	Brookfield RVF #3 sp. @ 4 rpm 14,000	Brookfield RVF #3 sp. @ 10 rpm 7,000
Mix Ratio: By Weight	1 Part	1 Part
Mix Ratio: By Volume	1 Part	1 Part

Work Life (Approximate time for a 100 gram quantity @ 75°F.): 90 min.

TABLE B-2. "SCOTCH-WELD" PERFORMANCE CHARACTERISTICS

1. Overlap Shear Strength (PSI)
   ASTM D-1002-64

Test Temp.	Aluminum FPL Etch
-67°F.	3,000
75°F.	1,200 (a)
180°F.	200

2. T-Peel Strength (PIW)
   ASTM D-1876-61T

Test Temp.	Aluminum FPL Etch
75°F.	25

(a) Scotch-Weld Brand Structural Adhesive 2216 B/A Clear will develop an ultimate overlap shear strength in excess of 2000 psi if allowed to cure 30 days @ 75°F.

(b) Data developed using 7 day cure @ 75°F., 2 psi.

APPENDIX C. TENSILE AND PROOF LOAD TESTS, APEX FITTINGS

Osborne LABORATORIES, INC.

[illegible] CLARK STREET • SANTA FE SPRINGS, CALIFORNIA [illegible]

(213) [illegible] • (213) [illegible] • (714) 523-1941

Report to: Fiber Science
259 East 157th Street
Gardena, California 90248

Attention: Henry Brown - Fiber Science

Project: APEX FITTINGS

Subject: Apex Fittings - Army Helicopter
Kevlar 29

Laboratory Number: T8-09-076

Date: October 9, 1978

At the request of Mr. Henry Brown of Fiber Science, our laboratory performed Tensile and Proof Load Tests on various sizes of Apex Fittings. Testing was performed on 10/2/78, 10/5/78, 10/6/78, and 10/9/78.

Results are as follows:

Sample Identification	Load, lbs.	Remarks	Date
#3 25k	71,000	Ultimate	10/2/78
#4 25k	87,000	Ultimate	10/2/78
#5 25k	85,000	Ultimate	10/2/78
#6 25k	72,000	Ultimate	10/2/78
#7 25k	67,000	Ultimate	10/2/78
#8 40k	98,500	Ultimate	10/2/78
#9 40k	134,000	Ultimate	10/2/78
150# 1	124,000	Ultimate	10/5/78
200# 3	110,000	Ultimate	10/5/78
240# 1	152,000	Ultimate	10/5/78
120# 8A	78,000	Ultimate	10/6/78
240# 2	177,000	Ultimate	10/6/78
200# 4	71,000	Ultimate	10/6/78
160	118,000	Ultimate	10/9/78
250	115,000	Ultimate	10/9/78
160	37,000	Proof Load	10/9/78
160	37,000	Proof Load	10/9/78
250	60,000	Proof Load	10/9/78

Respectfully submitted,
OSBORNE LABORATORIES, INC.

F. Rob

Frank B. Robison
Professional Engineer

FBR/km:2

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